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THERMAL INSULATING SYSTEM FOR GAS REACTOR CONCRETE PRESSURE VESSELS

by

G. BLANCHARD, S. CRUTZEN and F. FARFALETTI-CASALI

1973



Joint Nuclear Research Centre
Ispra Establishment - Italy

Technology Division

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Luxembourg, August 1973 — 18 Pages — 19 Figures — B. Fr. 40,—

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The principal features are:

- system particularly suited to be optimized in an Helium atmosphere
- structure completely prefabricated remarkable for its lightness, that is ratio of material weight over volume.

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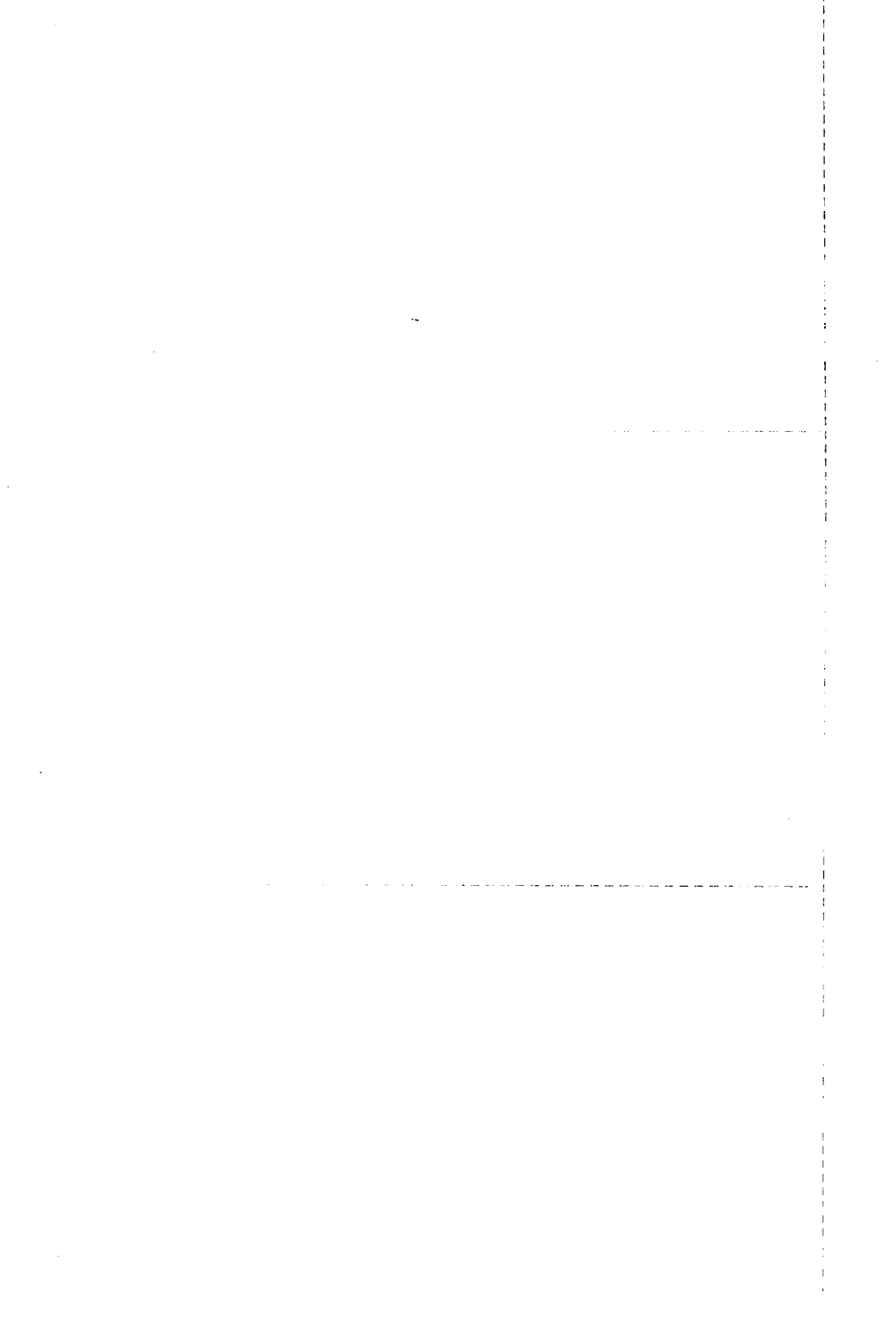
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SUMMARY

This report gives a general survey of thermal insulation system for prestressed-concrete pressure vessels and primary circuits, studied in the Technology Division of the Euratom Joint Research Center under the HTGR programme.

The principal features are:

- system particularly suited to be optimized in an Helium atmosphere
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KEYWORDS

PRESSURE VESSELS
THERMAL INSULATION
PRESTRESSED CONCRETE
GAS COOLED REACTORS

1. INTRODUCTION *)

1.1. Necessity and Principle of the Insulation of Concrete Pressure Vessels ¹⁾

The prestressed concrete vessels developed for graphite-gas reactors are particularly suitable for the construction of large nuclear power-stations and their use has been extended to high temperature gas reactors.

Due to the bad behaviour of concrete at high temperature a thermal insulation of the internal surface of the vessel has to be provided, as well as a cooling circuit. Moreover, the porosity of the concrete means that this internal surface must be covered with a leak-tight liner.

Two schemes can be envisaged, according to the relative positions of the insulation structure and the leak-tight liner:

a) Internal Insulation (cold liner) — (Fig. 1)

In this disposition, which is the usual one, the protection of the internal face of the vessel is composed, going from inside to outside, as follows:

- an eventual casing for mechanical protection of the insulating structure when necessary;
- an insulating structure;
- the liner fixed in the concrete and providing for the gas-tightness;
- a cooling circuit (water) generally welded on to the external face of the liner.

This solution simplifies and facilitates the mounting and behaviour of the liner remaining at low temperature. On the contrary, the insulating structure is in contact with the primary fluid and has to be designed taking the nature pressure and temperature of the cooling fluid into consideration; the heat transfer modes being a function of the considered zones of the vessel (roof, lateral walls...) the structure has to be designed for each zone where to be applied.

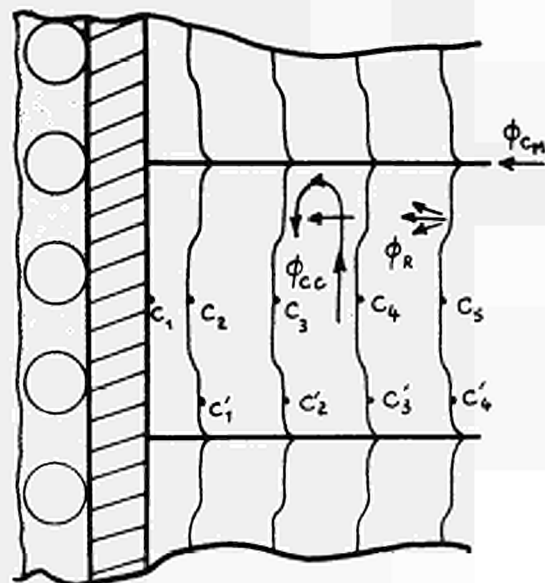
The compatibility between the reactor coolant fluid and the insulating structure must be taken into account. Moreover, the insulating structure must withstand rapid accidental depressurisations.

b) External Insulation (hot liner)

In this conception, the insulator is no longer in contact with the coolant and the insulation structure could be more classical.

The liner, leak-tight and therefore without discontinuities, is submitted to great temperature variation and the dilatations have to be absorbed; its behaviour becomes very critical. This solution is not admissible, as the fluid temperature increases (HTGR).

Only the first-mentioned configuration will be considered here, in particular as regards its application to the High Temperature Gas Reactor.



- ϕ_R radiation flux
- ϕ_{CC} convection and conduction flux in the gas
- ϕ_{CM} conduction flux in the lateral walls

Fig. 1: Internal Insulation (cold liner).

*) Manuscript received on May 28, 1973

1.2 Insulating Structures for Gas Reactors

1.2.1 The PUMICE CONCRETE was studied as thermal insulation for the EDF 3 and EDF 4 reactors. It is made of aggregates of pumice and artificial portland cement. The insulating wall was protected by a steel casing; in case of rupture or fissuration of this casing, pumice and cement powder present a danger for the primary reactor circuit ²):

1.2.2 The use of GLASS or SILICE FIBRES was studied by the Saint-Gobain Company; these fibres were contained in rectangular metallic cells ³).

CERAMIC FIBRES were also utilised for the Fort-St. Vrain power Station ⁴).

Depressurisation problems concerning the insulating structure protection always arise when utilising fibres.

1.2.3 The metallic insulating structures utilise the insulating properties of the reactor coolant itself when reducing the convection movement as much as possible by good structure design.

Different types of metallic structures were developed, but for helium cooled reactors the optimised solution for CO₂ cannot be directly extrapolated because of the great differences in specific weight and thermal conductivity between the two gases. The insulating structure corresponding to the best compromise between conduction in the coolant gas confined by this structure, the convection movements of the gas, the radiation heat transfer and the conduction in the metallic walls of the structure, seems to be a metallic cellular structure (Chap. 5), at least up to temperatures of the order of 700°C.

The "DARCHEM" structure ^{5,6}), the "HONEYCOMB" type structures, developed by the "Sud-Aviation" Company ⁷), the "ONDULINOX" insulator ⁸) and the "CALD" structure ⁹) show that difficulties always arise with the absorption of thermal dilatations and the assembly of the structure in the reactor vessel: special sealing systems are necessary and the mounting time and price could be very high. The cell dimensions are far from the optimum requested by working conditions in helium at rather high pressure (Chap. 5) and big convective movements (macro-convection) appear in the entire structure due to the lack of tightness between the elementary cells combined in series and in parallel.

1.3 Cost Evaluation of the Metallic Insulating Structure

Thermal insulation presents an important percentage of the cost of the concrete vessel of the order of 25% by some estimates. From a reliability point of view, it is an essential component which must retain its integrity during the life-time of the reactor.

The design of a satisfactory insulation system apparently involves many different aspects, not only to the thermal characteristics of the cooling gas have to be taken into account, but also such problems as compatibility and corrosion of materials, vibration of the structure, transient operating conditions (accidental rapid depressurisation), and assembling time in the vessel which incides significantly on the costs.

As an example, the total cost of the thermal insulation could be divided into four main parts.

1.3.1.C.I: The thermal losses ϕ_T (on figure 2) as a function of the efficiency of the structure (thickness e of the insulator).

1.3.2.C.II: The material and production costs depending on the insulation type and thickness.

1.3.3.C.III: The vessel diameter increase due to the thickness of the insulating structure.

1.3.4.C.IV: The assembly costs which take into account

- the covering of the liner
- the immobilisation of the construction of the plant for this assembly work.

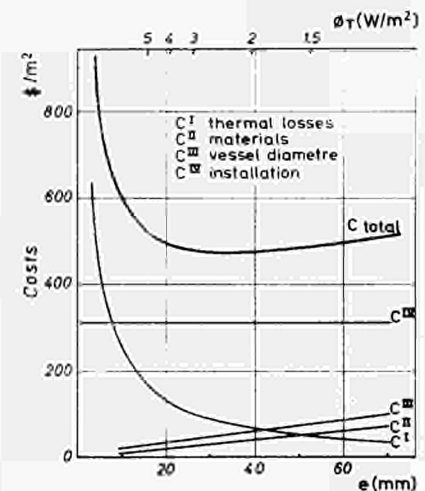


Fig. 2: Example of cost evaluation.

This cost can be considered to be independent of the thickness of the installation of some parts of the structure, which are prefabricated.

Fig. 2 gives an idea of the relative value of each of these costs and shows the flat optimum occurring in the curve CT: total cost as a function of the thermal losses.

2. DESCRIPTION OF AN ORIGINAL SOLUTION

2.1 Introduction

At the Euratom Joint Research Centre, some original insulating systems are being studied or are already under development, which are particularly suited to be optimized in an helium atmosphere and whose main characteristics are:

- a low weight (in the order of 20 kg/m^2); a relatively low number of thin metallic foils is used, thus allowing refractory materials to be employed, and permitting higher temperatures to be withstood, without incurring prohibitive costs.
- A completely prefabricated structure: all thermal dilatations of the insulating panel are absorbed by the structure itself without geometrical change of the outer perimeter. This characteristic permits fabrication panels which can be mounted one beside the other and one behind the other, without it being necessary to have overlapping insulating layers along the perimeter of the structures. This offers a double advantage i.e. simple mounting of the panels and elimination of the risks of clamping and seizing that are found in solutions needing some overlapping among layers¹⁰).

2.2 Insulating Pannels for the Cylindrical and Plane Surfaces of Concrete Pressure Vessels.

These panels are intended for the lagging of large continuous surfaces, i.e., the plane surfaces of the floor and ceiling and the cylindrical surfaces of concrete pressure vessels.

As far as the description of the panels is concerned, cylindrical surfaces having a large radius of curvature (up to 10 m.) can be considered plane surfaces. Later on we shall examine the problems encountered in the construction and installation of insulating panels for cylindrical surfaces. Lagging panels for concrete vessels must fulfil the following conditions:

- they must thermally insulate the concrete of the vessel (temperature 50°C) from the atmosphere in the reactor (temperature 350°C , pressure approx. 40 atm), giving a thermal-loss of the order of 0.2 W/cm^2 ;
- they must withstand depressurization rates of the order of 20 atm/sec (accident conditions);
- they must resist repeated thermal and pressure cycling.

2.2.1 Original Metallic Cellular Structure

According to this method the thermal insulation named "CASALI" type insulation, consists of superimposed cells (between 6 and 10 in number) containing static gas, which are attached to the steel liner of the pressure vessel.

The number of cells depends on the pressure, on the temperature difference between the reactor atmosphere and the liner and on the nature of the gas. Theoretical calculations show that in the case of helium the insulating effect can be obtained with a small number of cells of relatively great height, i.e. 5-10 mm. With this gas the convection phenomena are of minor importance.

In Fig. 3 the steel liner, which constitutes the leak-tight skin of the pressure vessel is indicated by item (1). It consists of a welded, continuous, thick plate which covers the flat heads and the internal cylindrical surface of the concrete.

As stated above, we shall first consider the case of the plane surfaces.

The liner is cooled by water circulation throughout tubes embedded in the concrete, so that the average temperature of the liner, and hence of the concrete, is about 50°C . Item (2) in the figure shows the locating lugs for the fixing studs of the insulating panels (diameter approx. 12 mm., height 10-15 mm). These are welded on the liner in a staggered pattern, with a pitch of between 300 and 600 mm. The metal structure illustrated in Fig. 3 is composed of a number of cells assembled in the workshop to form the actual panels.

The dimensions of the panels are limited by the problems of handling and of mounting them on the cylindrical surfaces.

Installation inside the vessel is a very simple operation: it is done by placing the panels on the locating lugs (2) and fastening them by means of the studs (3), which are locked in position either by crimping or by welding. The studs are hollow in order to minimize the heat-transfer paths to the liner.

The joints between different panels can be as shown in Fig. 3, in which they are indicated by a heavy zig-zag line tracing the perimeter of the peripheral cells of the panels.

Since the thermal dilatations of each cell are taken up by the cell itself, the panels can be fitted without any clearance and the lips of the foils along the join can be spot-welded after installation to eliminate thermal leakage between the panels due to convection.

Near the tube inlets or near the intersections of surfaces, i.e., where the panels have to assume a particular profile, the cells can be cut and blanked off with sheet metal. We would point out that in certain singular points and in certain surface intersection zones, where high gas velocities will be encountered, our insulating structure can be lagged by means of some smooth hot-side cover plates, as we shall see later on.

The construction and fitting of the panels are just as easy in the case of cylindrical surfaces.

The panels, 2-3 m. wide, will be assembled in the workshop to the desired radius of curvature (e.g., on a model) from the same standard foils as are used in the construction of flat panels. As is clearly apparent from Fig. 3, the metal foils are slightly deformable in the plane between the locating holes owing to the presence of a central undulation. This undulation, moreover, enables the distance between the holes to be varied slightly.

On the other hand, the elements (4) which make up the lateral walls of the cells can be cut along the liner side so as to follow the curvature of the latter.

The mounting of the panels on the locating lugs (2) inside the pressure vessel is rendered possible by the clearance of these lugs in the holes (10).

2.2.2 Description of the Metallic Cellular Structure

Fig. 3 illustrates the metallic structure of the panels in the case of plane surfaces.

The structure is composed of thin sheet-metal stampings, 0.2-0.5 mm thick, in stainless steel or in a stainless Ni-Cr alloy. The various elements making up the panel are electrically spot welded together, in order to increase the rigidity of the structure.

Nevertheless, a characteristic of our solution is that spot-welds are not necessary; in fact, tests demonstrated that, a panel of this type can be mounted without use of spot-welds. Thus, the breakage of some or all spot-welds does not seriously endanger the performance of the panel.

The first part of the structure comprises the lateral walls (4) of the cells, perpendicular to the liner. They are bent into a 90° V between main walls.

Where the panels are required to cover a vertical surface, the lateral walls are arranged horizontally side by side and form several parallel rows, thus constituting the boundaries of cells which are approximately square in shape and between 200 and 500 mm wide.

The elements (4) are joined together by spot welds on the bridging pieces (5), which are attached and located by the lugs (2).

The insulating cells are completed by the metal foils (6), which are arranged one beside the other inside the cells enclosed by the walls (4). These foils are identical and are constructed as shown in Fig. 3.

Each foil has an undulation (7) running diagonally across it and a second, non-continuous undulation (8) at right angles to the first. These undulations allow thermal dilatation of the foils and at the same time increase their transverse rigidity.

The foils are provided all the way round with edges (9) which bear against the walls (4) of the panel, to which they are spot-welded to give a non-leaktight joint.

The purpose of the edges (9) is to reduce the gas convection movements between the various cells whilst still allowing a flow to take place during depressurizations.

Each foil has two holes (10) to take the locating lugs (2) and the hollow studs (3) on which the foils are stacked. On either side of the locating holes it is proposed to leave slits between adjacent foils to facilitate the depressurization of the panels.

The distance between the superimposed foils of a cell, which represents the height of the insulating cell, is in the order of 5-10 mm. It is maintained by two semicircular edges (11) on each foil, at right angles to the holes (10), and by the two raised tabs (12) at each end of the undulation (7).

Four slits (13), which could be situated at the intersections of the corrugations (7 and 8), would facilitate rapid depressurization under accident conditions by allowing the sheet metal to deform, whilst nevertheless preventing strong gas convection movements between the cells during normal operation.

Normally, these slits are not provided, because they are not strictly necessary in normal operation conditions.

The last foil (6) of each cell, which, like the foils enclosed in the cell, has its edges spot-welded to the wall ends (4) constitutes moreover a protective casing for the panel and can be made of heavier-sheet metal.

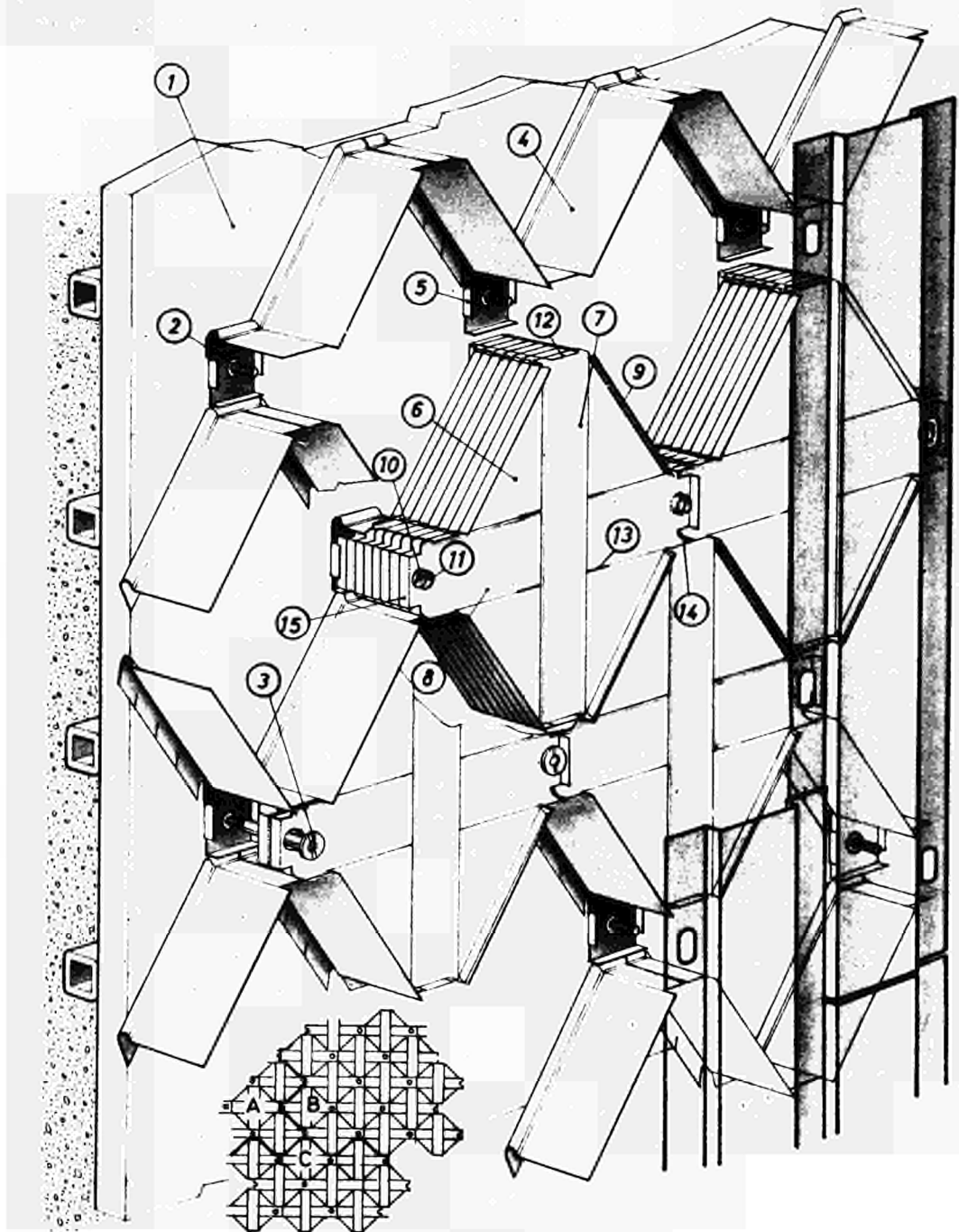


Fig. 3: Metallic cellular structure.

2.2.3 Arrangements to Avoid Parasitic Convective Flows in the Metallic Cellular Structure

The proposed solution has been initially studied for lagging internal vessel surfaces, where in general the gas is stagnant or flows slowly, and where the pressure differences in the points of lagged surface are small.

However, it may occur that in some points of internal vessel surfaces there are pressure differences and gas flows in contact with insulating panels which cannot be ignored. This can produce parasitic flows inside the panels and between the panels and the vessel liner and induce vibrations on the exposed surface of the panels.

In fact, in our structure, the lateral walls (4) prevent gas flows among insulating cells in vertical direction completely, but only partially in horizontal direction, owing to passages between adjacent cells near the holes (10).

Moreover, should the liner's inner surface be irregular, difficulties could be encountered in fitting the panels to the liner. There would consequently be a risk, especially on the vertical cylindrical surfaces, of gas convection movements between the liner and the panels. In the points where these phenomena can occur, it is advisable to predispose some of the following arrangements:

- to reduce parasitic flows between liner and panels, the lateral walls (4) can have, on the side of the liner, a fringed edge appropriated to collapse against the irregularities of the liner, during assembly of the panels.
- To reduce parasitic flows between adjacent insulating cells in horizontal direction, the passages near the holes (10) can be throttled further on by placing at these points flanged edges between the different foils. Moreover, in the joints between adjacent panels, these passages can be easily closed by putting some pieces of metal sheet along the contour of the panels.
- To reduce the risk of vibrations and gas pressure losses along the hot face, it is advisable to reduce the height of the edges on the last hot foils of the panel. Where this arrangement is not sufficient, some smooth hot sided/ COVER plates/ can be added to the panel. These cover plates can be fastened by the same studs used for the panels. An example of application of cover plates on our insulating structure is given in the attached figure 3.

2.2.4 Composite Insulating Structures

Two variants of the technique described in the foregoing paragraph are possible. The first one is the use of insulation panels having the same metalbased structure but in which the stacked foils (6) are replaced by an insulating element which is generally made of fibrous material. This element, which has the shape of the cell in which it is to be inserted, can consist, for example, of a blanket of mineral or ceramic fibres, possibly enclosed in a metal fabric.

Such fibres are already in commercial production, they are generally based on silica and alumina, examples being "Kaowool", produced by the firm of Babcock & Wilcox, and "Kerlane", made by Société Générale des Produits Réfractaires. Above the insulating blanket is placed a metal foil which is identical to the foils described in the preceding section and is fixed in the same way to the edges of the walls (4). It thus serves to complete the metal structure of the panel and to enclose the insulating blanket in the cell.

By this technique it is possible to construct insulation panels with very small metallic parts, owing to the small thicknesses required. One can consequently consider using very expensive but highly refractory alloys and metals capable of withstanding without damage temperatures of the order of 900-1000°C on the hot surface (Hastelloy X, Inconel alloys and also refractory metals such as niobium, molybdenum, etc.).

Furthermore, the use of suitable thicknesses of mineral fibres possessing very good insulating properties opens up the possibility of panels which would directly insulate a space in which the temperature is in the region of 900-1000°C, with a temperature difference of 800-900°C between the hot and the cold surface of the panel.

A second variant of our insulating systems is foreseen for very high temperatures, more than 1000°C on the hot surface. This variant foresees the utilization of modular pieces made in insulating refractory material, such as Silicon Nitride or special Carbon and Graphite products.

These insulating materials are normally very expensive, and consequently it seems impractical to construct the insulation with them alone.

At a lower temperature, the part of the insulation adjacent to the liner, can be realised by a metallic cellular structure, such as that described in the preceding paragraphs.

On this structure it is possible superimpose some insulating pieces of adequate thickness, having approximately the shape of the underlying metallic cells, but with such steps on the boundaries that every direct passage from inside the reactor to the metallic parts of the insulation, including the fixation system of the insulating pieces themselves is prevented.

In this way it is possible to conceive of an insulation system with no metallic parts directly exposed on the hot side.

2.2.5 Systems Welded Directly to the Liner

A structural variant, which can be applied to the metallic parts of our insulating systems, is that in which the walls (4) of the cell are used for joining the insulating structure directly to the liner (1) of the pressure vessel.

The locating lugs (2) and the hollow studs (3) can then be omitted. Obviously, the elimination of the locating lugs and the hollow studs also does away with the corresponding hot-spots on the liner. Two solutions are possible along the line.

In the first solution, the walls (4) are joined to the liner by means of bridging pieces (5) which are resistance-welded to the liner. The panels are completely pre-assembled, as in the preceding solutions, the only difference being that the bridging pieces (5) have no locating holes and adhere firmly to the liner when the panel is applied. In order to weld the panel to the liner it is merely necessary to insert the electrode directly through the holes (10).

In the case of the metallic cellular structure the semicircular supports (11) between the various foils also serve as partitions between cells.

A second solution permits the holes (10) in all the foils (6) to be eliminated.

This solution is particularly suitable for application in the case of a liner with a very irregular surface, and also represents another possibility for reducing parasitic convective gas flows, between liner and panels (cfr. paragraph 2.2.3).

The panels are fabricated in the shape indicated by item (B) in the figure 3, but with dimensions reduced to enable the panels to be fixed only along the outer perimeter.

Two edges of the panel (i.e. the lower and the left one) are fixed to adjacent panels already mounted by spot-welding of the lateral walls (4) in contact along these edges. The two other edges of the panel (i.e. the upper and the right one) are fixed directly to the surface of the liner by the lateral walls (4) that have, in contact with the liner, flanged boards that can collapse and can then be spot-welded against the surface of the liner, during mounting.

3. MANUFACTURING AND INSTALLATION PROBLEMS OF THE ORIGINAL STRUCTURE

3.1 Our general solution does not present any serious manufacturing problem. The most difficult parts to produce are the corrugated metal foils, but however, these are all identical and are fabricated by stamping. The spot-welding of the various elements is similarly easy to carry out. It is therefore clearly apparent that the manufacture of the insulation panels described above is based on techniques which are well known and easily applied.

Two methods could be suitable for the installation of panels in the vessel:

- a) the installation of panels which are attached to the liner by means of hollow threaded studs, at least not in the case of plane surfaces such as the flat of the pressure vessels, are preassembled to the maximum dimensions consistent with ease of handling inside the vessel; the installation work in the vessel consists merely in welding the locating lugs (2) to the liner and in fastening the panels by tightening the hollow studs (3).

Installation on the cylindrical surfaces of the vessel is carried out in the same way, but in this case the width of the panels in the plane of curvature must be limited to 2-3 m.; there is no limit to the height.

- b) The operations are further simplified if it is desired to weld the panels directly to the liner. It is then merely necessary to bring entirely prefabricated panels into the vessel and to weld them electrically to the liner. Compared with other solutions, the use of large prefabricated panels also has the advantage of enormously reducing the period of unavailability of the pressure vessel and, consequently, the ultimate costs of the insulation work.

3.2 Fixation of the Prefabricated Panels on to the Liner

3.2.1 Fixation by mean of Locating Lugs Welded on to the Liner

At Ispra, the locating lugs were welded in usual way with argon-arc. This operation is relatively easy as the liner is rather thick.

For industrial application, it is intended to use automatic or semi-automatic welding methods. Some solutions were studied for application to hollow locating lugs. Methods using special lugs with fondant at the extremity were eliminated because of cleaning difficulties, corrosion danger or economic reasons.

The most suitable solution seems to be the capacitive discharge welding system which allows weldings of stainless steel or carbon steel lugs up to 8 mm diameter.

Systematic tests are to be performed in order to insure

- the possibility of welding hollow lugs with regard to the real material used for the liner
- the possibility of performing these welds throughout the structure in order to avoid assembling and dismantling the panels for the fixation points on the liner tracing
- the reproducibility of the results.

3.2.2 Fixation of the Panels by Spot-welding of the Lateral Walls of the Structure Directly on the Liner.

The direct fixation of the lateral walls (item 4 on figure 3), by spot-welding on the liner was tested and applied for two reasons:

- fixation without locating lugs avoiding hot points on the liner
- better leak-tightness between the insulating structure and the liner (reduction of the macro-convection).

This solution was tested with regard to the local roughnesses of the liner (discontinuities, weldings...). The fringed edge of the lateral wall (Fig. 4) is suitable for direct welding on the liner; the values of R and L (Fig. 5) are to be chosen as a function of the roughness of the liner and of the welding tools.

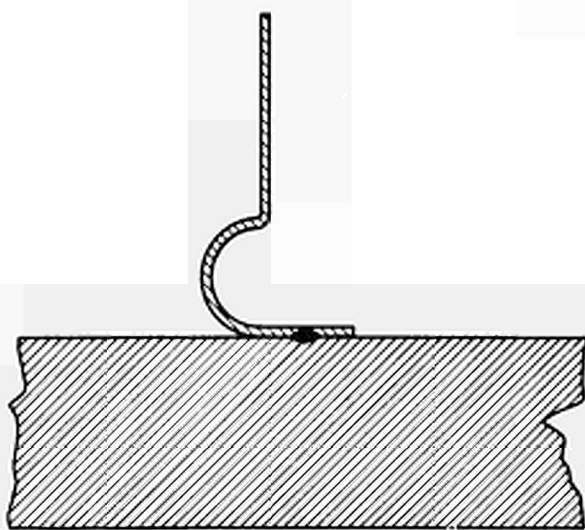


Fig. 4: Welding of lateral wall on the liner.

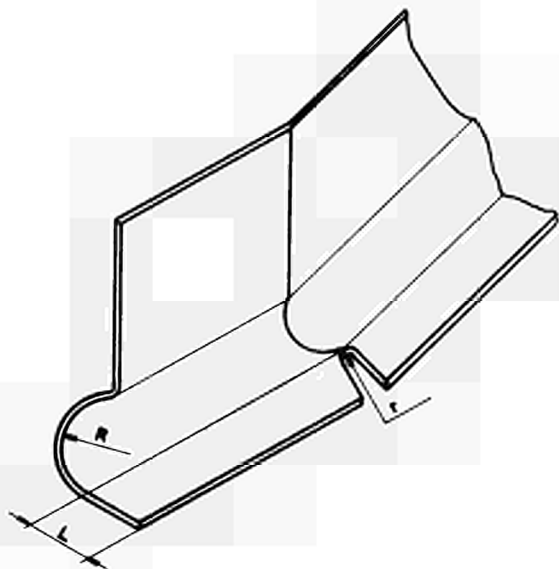


Fig. 5: Fringed edge of the lateral wall.

The conditions for assembling the structure following this method were:

- stainless steel 304L walls of 0.5 mm thickness on stainless steel 304L or AQ 42 steel liner 10 mm thick
- spot welding torch NERTAL (Argon - direct current)
- roughness of the liner simulated by
 - a) curved 340 mm long foil with a 4 mm dip
 - b) perpendicular non smoothed welding
 - c) oblique welding
 - e) 6 mm diameter stick between liner and wall.

The results were always satisfactory. No liner preparation is necessary for the assembly of the structure and the penetration of the arc was sufficient to ensure good weldings. The diameter of the weldings is variable following the manual pressure of the welding tool. Other tests are to be done on this last point; a magnetic steel liner (carbon steel) would give a more regular result having always the same predetermined pressure of the wall fringed edge on the liner.

This could be envisaged in an industrial optimisation of the method.

3.3 Fabrication of the Different Components of the Structure

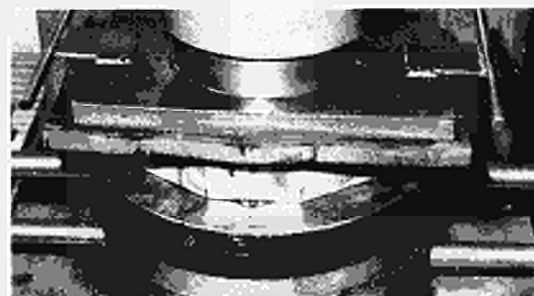
3.3.1 Fabrication of the Metal Foils (item 6 on figure 3)

The chosen dimensions of the metal foils, 350x300 mm are function of the existing fabrication tools.

The thin metal foils (0.2 mm) were stamped using an hydraulic press with rubber covered matrix (Perbunan of 10%, 60/65 shore).

The lubrication remains necessary as well as a mechanical positioning of the foils during stamping in order to avoid corrugation and slipping.

For an industrial application, stamping the foils and cutting the edges should be done in one operation.



Figs. 6 and 7: Matrix for stamping of metal foils.

3.3.2 Fabrication of the Lateral Walls (item 4 in Figure 3)

The lateral walls were stamped using an hydraulic press, modified in order to give the alveolar form and the fringed edge designed to collapse against the irregularities of the liner.

After crumbling the extremities and the fringed edge, the manual folding was done directly on the matrix in closed position.

The thickness of the walls was 0.3 mm.

Figures 9, 10, 11.

Industrially, these walls could be produced profiled as usual for later folding for obtaining the alveolar structure.

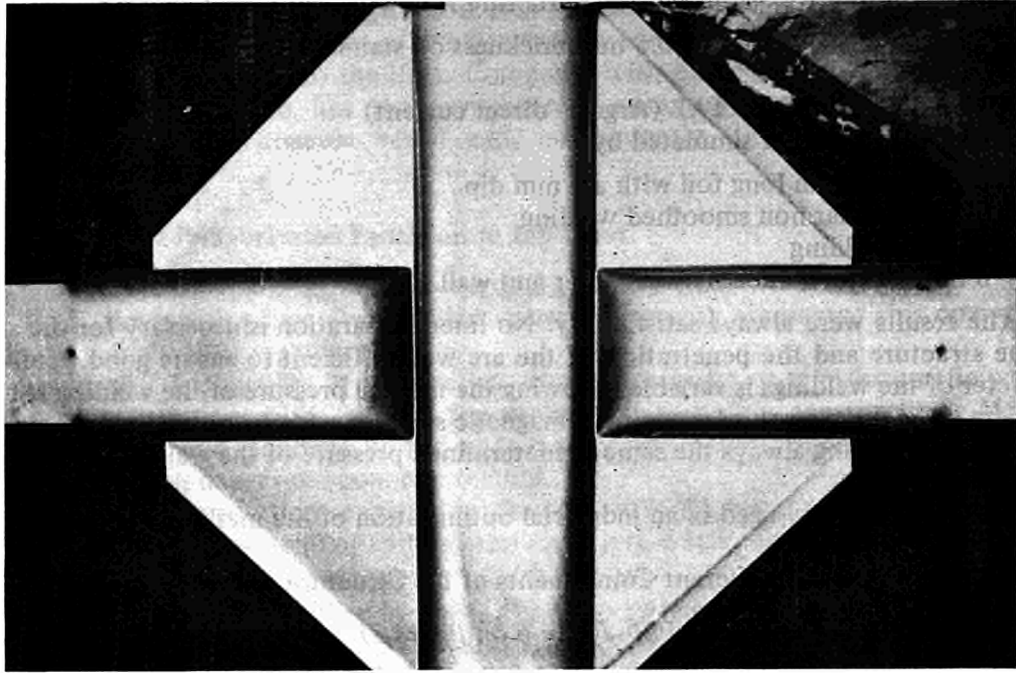


Fig. 8: Stamped metal foil.



*Fig. 9 and 10:
Stamping of the lateral wall.*

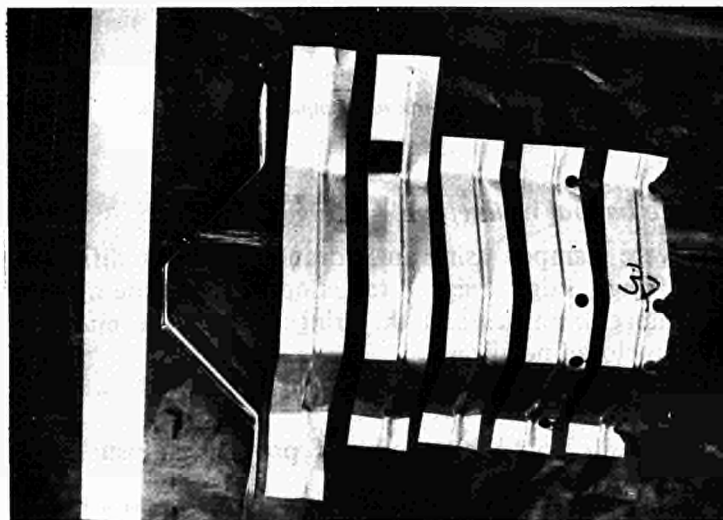
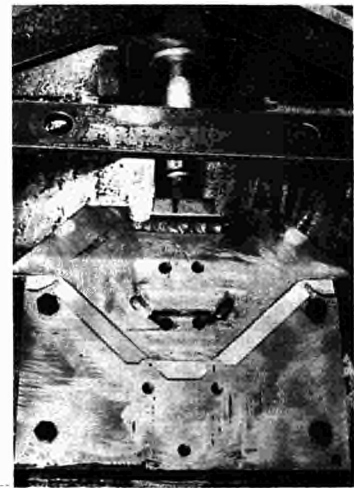


Fig. 11: Lateral walls.

3.3.3 Fabrication of the Bridging Pieces (item 5 on figure 3)

The bridges between the lateral walls were fabricated by classic stamping methods and were spot welded on to the lateral walls positioned on a former. The thickness of the bridges was 0.5 mm.

For industrial production, it would be useful to study the possibility of the bridges and lateral walls being of one single stamped piece. The material lost would cost less than that lost in positioning and welding the bridges between two lateral walls as was done for the prototypes.

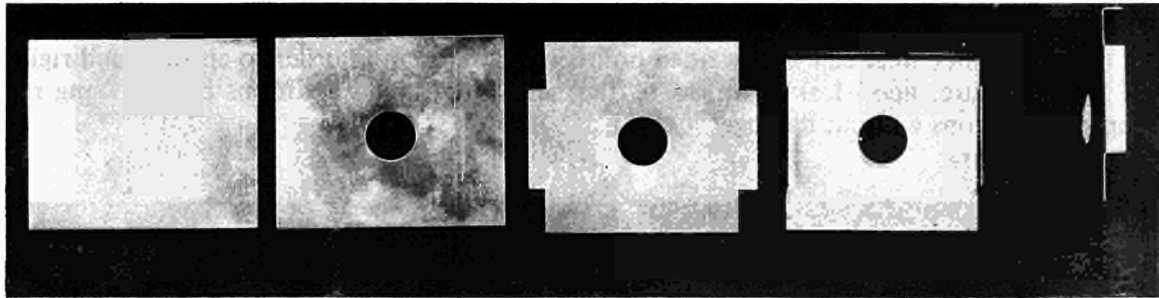


Fig. 12: Bridging pieces.

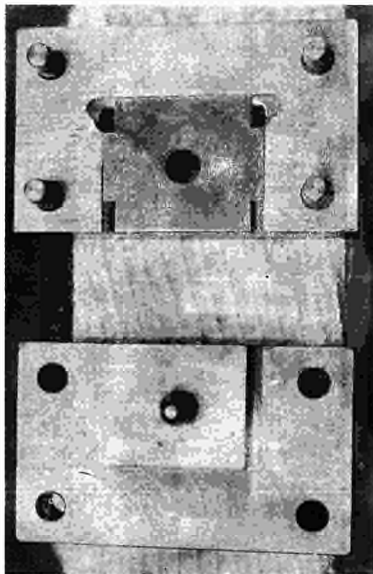


Fig. 13: Matrix for stamping of bridging pieces.

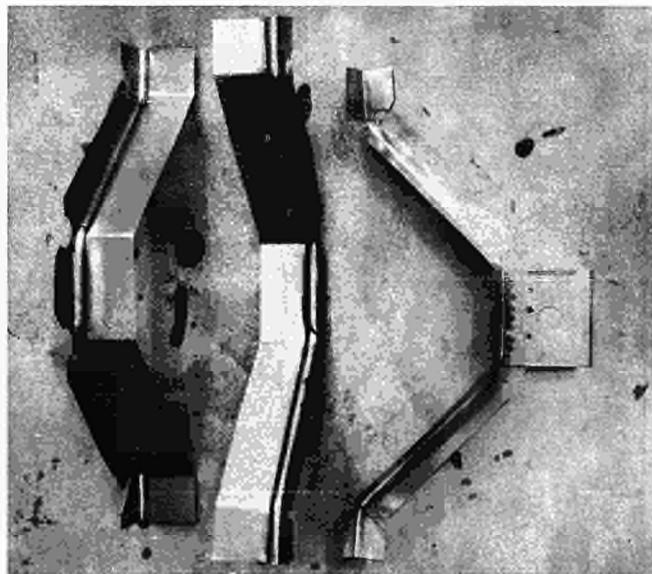


Fig. 14: Welding of the lateral wall and bridging piece on the liner.

3.4 Assembly of the Prefabricated Panels

3.4.1 Method used at Ispra for the Prototypes

The prototypes were not all assembled as prefabricated panels. For the different tests to which they were subjected, it was preferable to fix some of them definitively on a rigid liner allowing easier handling. Fig. 15.

However the first structure was made as an independent and rigid one, as a prefabricated panel would be. Fig. 16

For all the mounted structures, the assembly of the different pieces was done by spot welding along the fringed edges. The welds were obtained by capacitive discharge using two electrodes on the same side of the pieces to be welded together — Fig. 17.

The distance between two welded points was 3 to 5 cm in order to ensure good rigidity of the structure, good leak-tightness of the cells in normal conditions but allowing rapid depressurizations without damage.

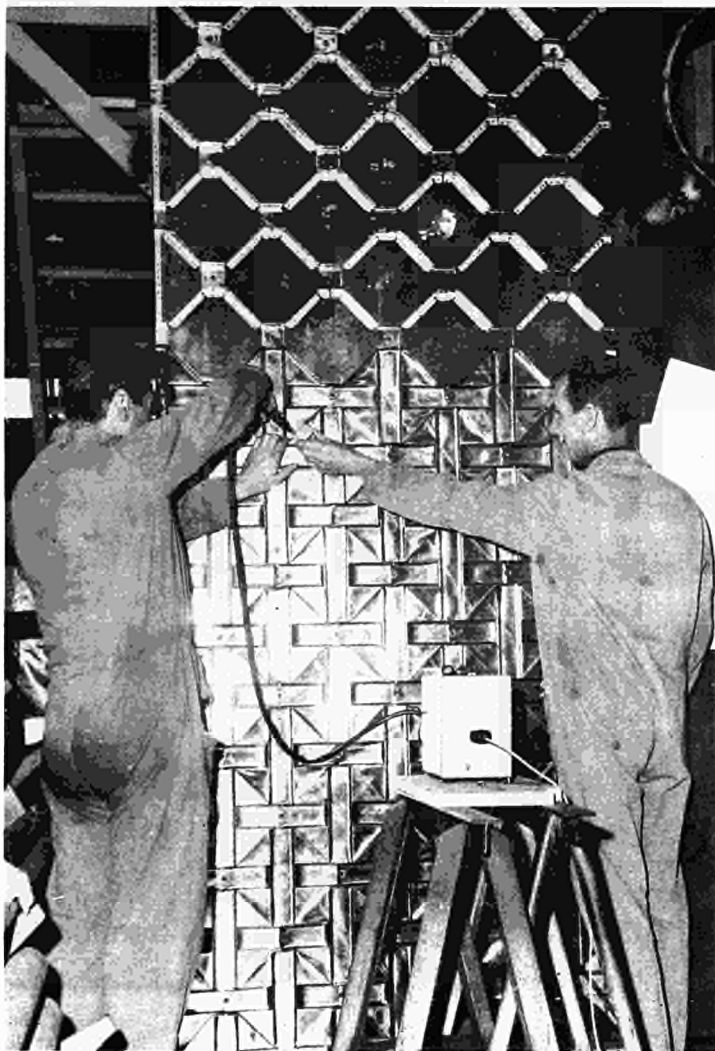


Fig. 15: Monting of the insulating structure on the liner.

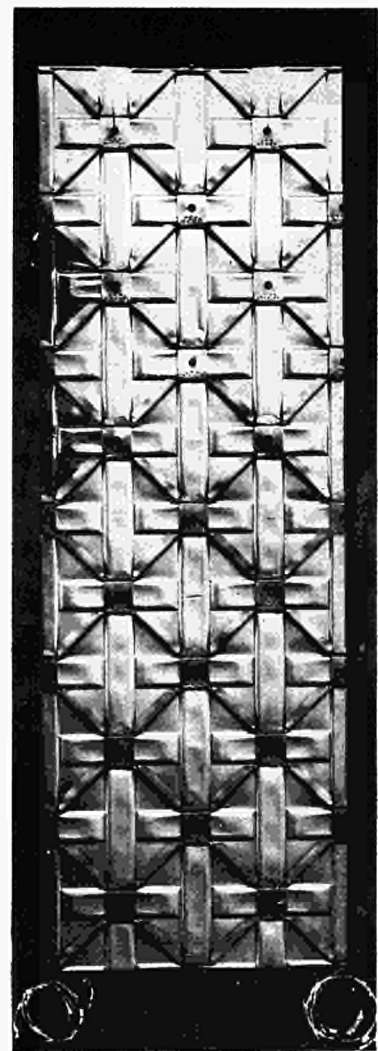


Fig. 16: Prefabricated panel for easier covering of the liner.

3.4.2 Method Envisaged for Industrial Applications

The welding method could be used for the prototype panels.

The prefabricated panels should have suitable dimensions for easy handling and application within the reactor vessel. This prefabrication has to be done in the work-shop.

Figure 18 shows the covering of the liner and gives a scheme of the special structures to be used for the last junctions and singular points.

This last structure is fabricated using half metal foils identical to those used for the general structure.

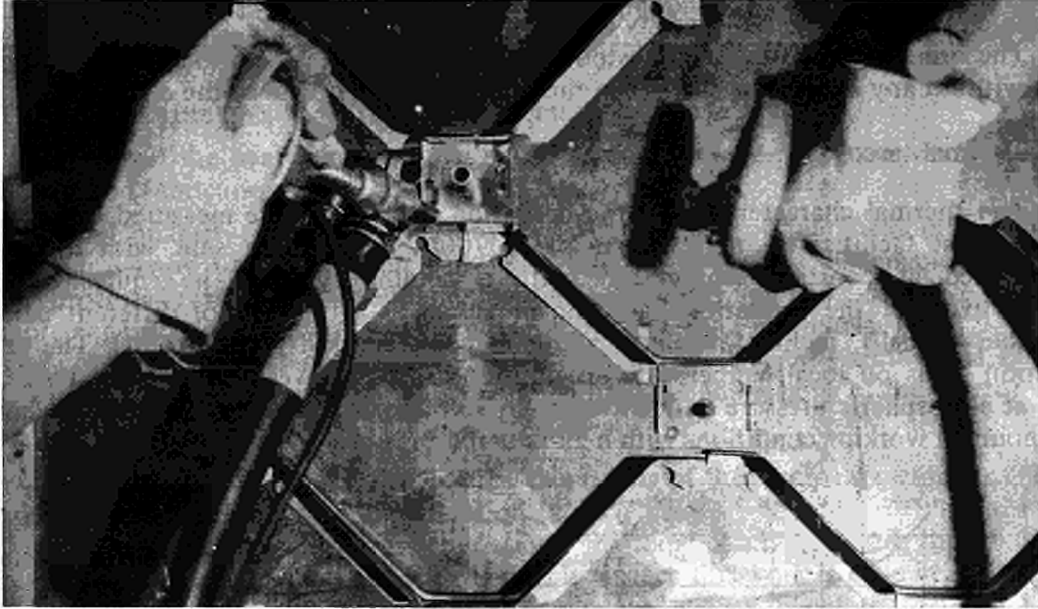


Fig. 17: Spot welding of structure on the liner.

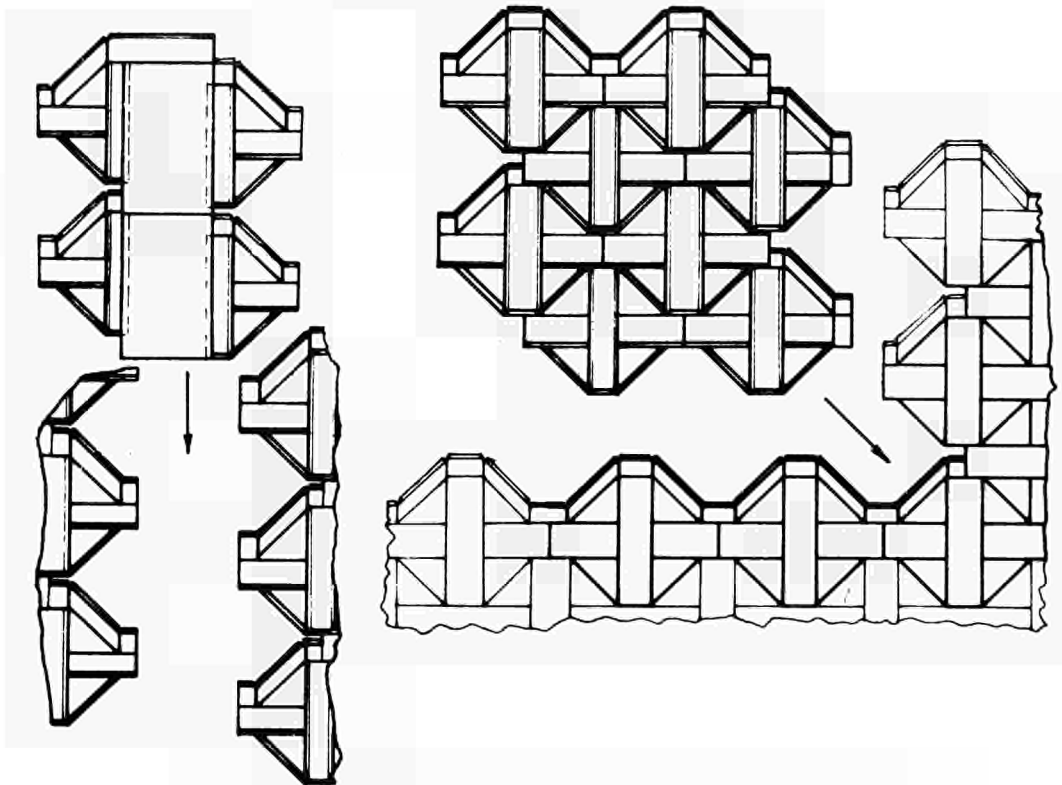


Fig. 18: Covering of the liner with prefabricated panels and last junctions.

4. TECHNOLOGICAL AND THERMAL TESTS ¹⁰⁾

4.1 Depressurization tests ¹¹⁾

One important transient condition concerns rapid depressurization phenomena in the case of a pump failure or, at the extreme, of a duct failure. In the gas duct, insulations must be able to withstand depressurization rates of the order of 20 atm/sec without damage to their integrity. At the Ispra Center a test facility was set up, in which rectangular (560x1500 mm) or cylindrical insulation specimens can be tested with initial depressurization rates of up to 100 atm/sec with helium or nitrogen. These tests are completed with different control tests such as metrology, radiography and permeability tests.

The original structure has withstood depressurization tests up to depressurization rates of 20 without any damage or changes in the relative leak-tightness of the cells.

4.2 Thermal tests ¹²⁾

The thermal characteristics of the insulation structures were measured experimentally in two test facilities up to temperature of 700°C on the hot side, with the cold side maintained at constant temperature with a cooling system. The equivalent thermal conductivity of the insulation has been measured as a function of different parameters (number of cells, inclination plane, width of cells, emissivity coefficient). The effect of fixation studs on local temperature distribution has been investigated. These tests, carried out at atmospheric pressure with nitrogen are extrapolated, using a GRASHOF similitude, for nominal working conditions with helium under pressure. Fig. 19.

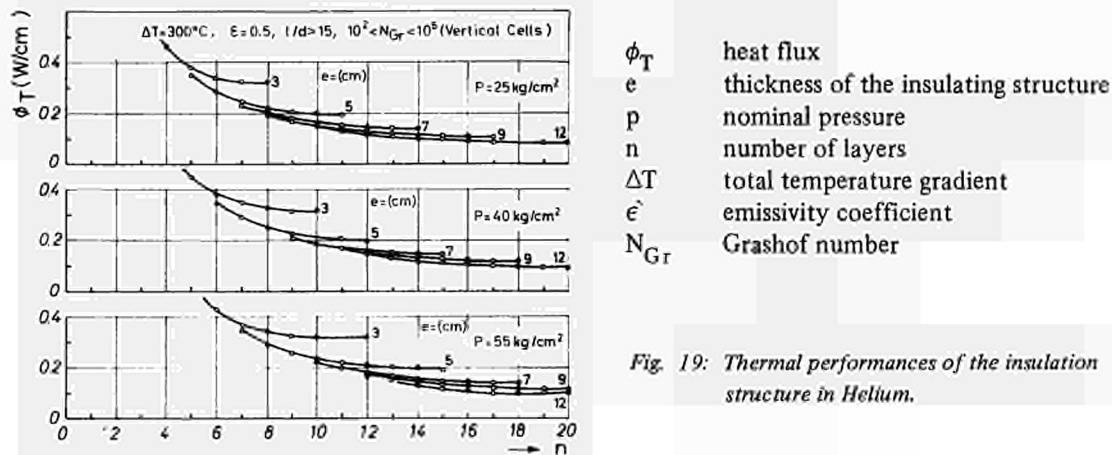


Fig. 19: Thermal performances of the insulation structure in Helium.

4.3 Thermomechanical and Aerodynamical Tests ¹³⁾

The insulation has also been submitted to 200 thermal cyclings with temperature variations of 300°C. Another test program: with pressurized gases is running, in which the insulation will be placed in a forced circulation of gas in order to study the influence of a longitudinal pressure gradient.

5. BASIC STUDIES AND CODES ^{14), 15)}

Mathematical codes have been made to calculate the heat transfer in rectangular insulation cells in series and in parallel, taking into account three simultaneous modes of heat transfer, by radiation, thermal conductivity and natural convection. These codes are used to optimize the design of insulation systems depending on the nature of the gas and the admissible heat losses. An experimental study has been made to check the validity of the theoretical analysis, particularly in the case of non-isothermal walls and in the low range of the GRASHOF numbers from 10^3 to 10^4 .

6. CONCLUSIONS AND ECONOMICAL ADVANTAGES

Our original structure designed for helium cooled reactor vessels presents some technical advantages allowing some reduction in costs;

- prefabricated panels without junctions (because of the thermal dilatations being absorbed by the structure itself without geometrical change of the outer diameter)
- low weight allowing easy handlings of the prefabricated panels
- minimum number of thin metallic foils enabling employment of refractory materials, and permitting higher temperatures to be withstood without running into prohibitive costs.
- classical methods of fabrication for the different components of the structure
- rigidity of the structure, good leak-tightness between cells, high resistance to rapid depressurizations and thus, reliability.

Turning to figure one, the different costs could be discussed.

- thermal losses: the heat flux is chosen and determines the number of layers (Figure 19).
- material and fabrication of the components:

the small quantity of material employed (about a third of that used in the metallic structures known to date), principally due to lack of a thick casing, enables the cost of the procurement of the metallic materials to be reduced and makes possible the use of more expensive materials such as the super-alloys or refractory metals.

The cost of the necessary dies for the stamping adds only slightly to the total cost if it is spread over the large number of pieces required for the lagging of the reactor vessel.

- assembling the structure in the reactor vessel.

generally the highest cost is the cost of the lagging of the reactor vessel because of the complexity and duration of the operation.

With prefabricated panels without junctions, this time can be reduced; the time taken to fabricate these panels is of lesser importance since this work is done in a work-shop, outside the plant.

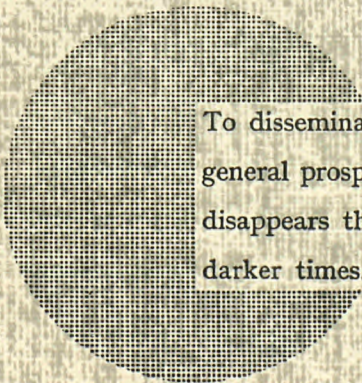
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